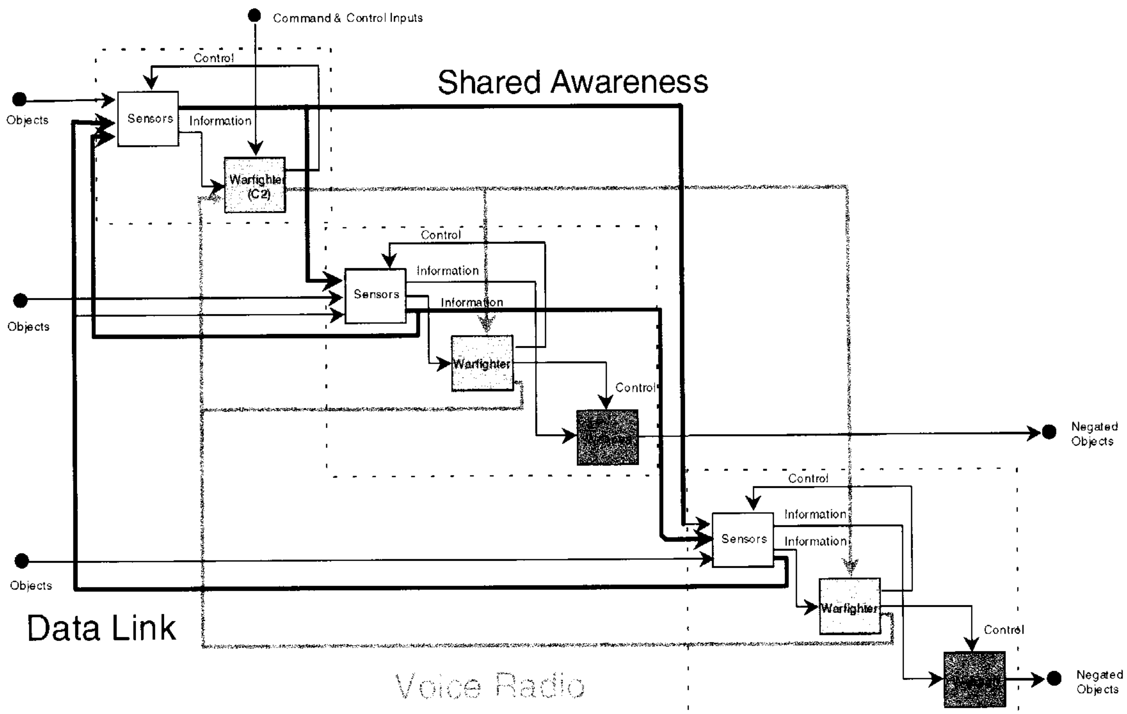


Figure 14. Network-Centric Operations

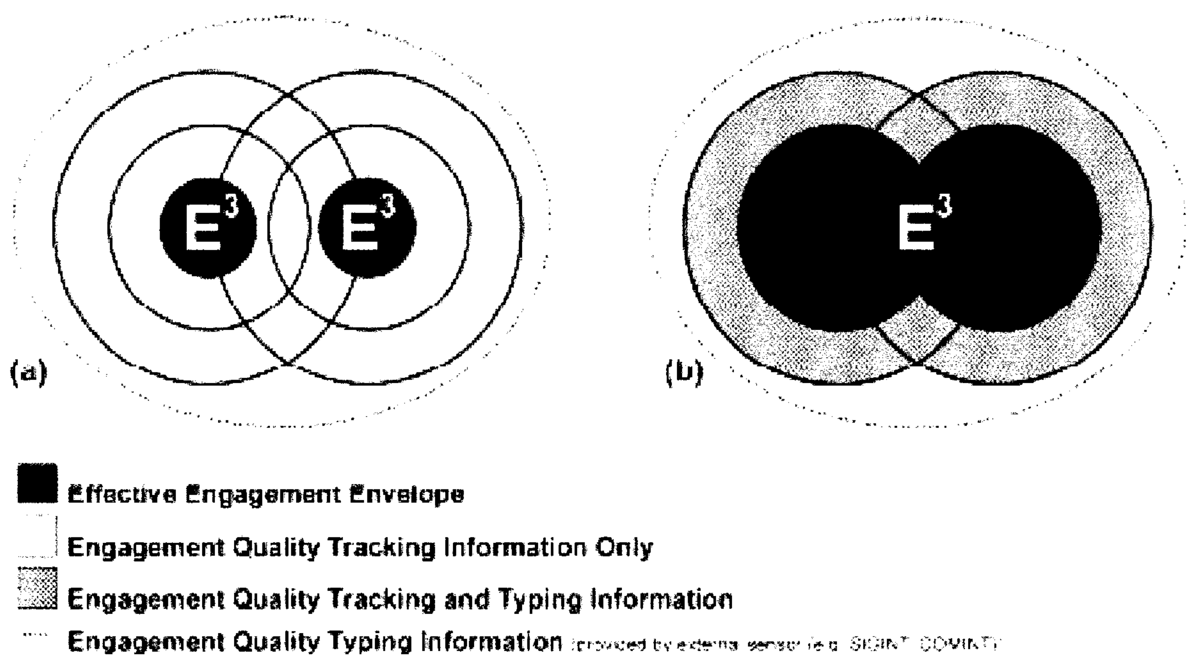


Figure 15. NCW Value-Added Combat Power

Figure 15 compares a case (a) that portrays two platform-centric shooters operating in close proximity, supported by an external sensing capability that can provide typing information. In this operational situation, real-time engagement information cannot be shared effectively and combat power is not maximized. In contrast, (b) portrays a geometric argument for the value-added combat power associated with a network-centric operation.

In this mode of operation, near real-time information sharing among nodes enables potential combat power to be increased. The robust networking of sensors provides the force with the capability to generate shared awareness with increased quality. This increase in awareness is proportional to the total area covered by the sensor zones. This increased awareness can be exploited by the robust networking of C2 and actor entities, which enables cooperative execution and self-synchronization of forces. The potential increase in total combat power associated with a network-centric operation is represented by the increased area of the effective engagement envelope. This simple example illustrates the application of Metcalfe's Law to military operations.

A word of caution is appropriate here. Metcalfe's Law is really about potential gains; there is no guarantee that simply hooking things up across the battlespace without appropriate organizational and doctrinal changes will increase warfighting effectiveness. In fact, there is every possibility that the unintended consequences of wiring up the battlespace and hoping for the best will, in fact, degrade performance particularly if doctrine, organization, training, and other key elements of the process are now changed to take advantage of the new configuration.[61] Therefore, the road to warfare based upon NCW needs to be richly populated with analyses and experiments in order to understand how we can reap the huge potential of NCW, while avoiding the pitfalls of unintended consequences.

The extent to which a network's productivity exceeds the sum of the productivity of its parts depends upon two things. The first is the gain that can be achieved by simply sharing resources (information) among the nodes. To illustrate this point, consider an example (over-simplified to make the point) in which organizations or individuals are distributed globally, each having a relatively small probability of possessing a given piece of information that is needed to make a plan successful. Let us say that this probability is 5 percent. If the planner only has access to organic information, he would only have a 5 percent chance of generating a successful plan. If the planner has access to the information that is available to a second organization, the chance he would get the information he needed to make the plan successful would be about 10 percent.

In general, for n sources the answer is $[1-.95^n]$. For n=5, the probability of having the information necessary to develop a successful plan is .226; for n=10 it is .401; and for n=25 the odds start to look much better at .723. Obviously, not all organizations have an equal probability of having the needed information. This actually works in our favor, provided we use our knowledge about which organizations and individuals are most likely to have the information needed. Given the development of reach-back capabilities, anchor desks, and smart information collection plans (or agents), we can, using the power of a network, turn a very low probability of having the information we need to a relatively high probability event.

This is what most people think about when they think about the power of a network. But there is also a fundamental new hypothesis that suggests that unlocking the full power of the network also involves our ability to affect the nature of the decisions that are inherently made by the network, or made collectively, rather than being made by an individual entity. This may not be immediately clear since these collective decisions are often implicit, and therefore not very visible. They have not been studied adequately, the focus to date being on explicit decision making. What this hypothesis implies is that we need to focus more attention on the behavior of the networked entities rather than just studying and considering the behavior of individual entities. Findings from *Fleet Battle Experiment Delta*, which will be discussed in more detail later, lend support to this hypothesis.

It is axiomatic, given almost any problem (e.g., assigning actors to targets), that one can always do as well, if not better, if a constraint is relaxed (again the ability is there, not the guarantee). However, constraints are often used as a means to achieve ends that are often as important as the objective of the task at hand. For example, given the problem of assigning actors to targets, constraints on the options are often used as a means to reduce fratricide, even though they will reduce the number of targets killed and increase leakage. The goal of NCW in this case is to achieve a reduction in fratricide while minimizing the constraints placed upon the weapons. One way to achieve this is to make actors more knowledgeable and their weapons smarter by providing them with more information.

To illustrate the power derived from sharing information, take the problem of assigning targets to actors. This problem can be formulated either as a centralized (unconstrained) or a decentralized (constrained) problem. That is, either there is:

1) one decision maker with no constraints on the information or processing power available to this decision maker, or on the decision maker's ability to communicate; or
2) there are several decision makers, each with limited vision and limited processing power (the sum of which may actually exceed that of the single decision maker).

Let us consider the case where a single decision maker could have the collective knowledge of targets; a unified picture of the battlespace and the time needed to process all of the information and transmit targeting orders to each actor. Under these conditions, an "optimal" decision could be reached. The function of the network in this case is to bring together partial pictures, assemble them into a unified whole, and then convey the product of the decision-making process to each actor. In other words, the sensor nodes share their information with the decision node, which in turn shares the decision with the actor nodes. Reality conspires against us and we rarely, if ever, are able to centralize collection and decision making to this degree. Thus, we rarely make "optimal" decisions. To some the goal of centralized optimal decisions remains at the heart of their vision of the future. For us it does not.

We see the power of NCW being derived from empowering all the decision makers in the battlespace rather than just a few. The realities of complexity and battle tempo will drive us to this use of the network. The objective is to get all our players and assets into the game at the same time. The ability to hit many high-value targets simultaneously gives us the wherewithal to employ a strategy of shock and awe that can bring a situation to a conclusion far more rapidly than an attrition-based approach.

Thus, contrary to some expressed concerns, NCW does not inevitably take us down the road to centralized control. In fact, from the explorations conducted so far it seems to be taking us down the road to increased (improved) awareness for all players with more collaboration and decentralization in the form of self-synchronizing forces.[62] As we apply the concepts of NCW to the "management" of battlespace information, we can expect that, in absolute terms, everyone will be more knowledgeable about the battlespace of the future than even some, if not all of, the best-informed entities are today. In the future we can expect tactical level commanders will have a better understanding of both the big picture and the local situation than operational level commanders currently have today.

The potential for information overload is real and great care must be taken to make sure that what is provided is actually information and not noise.[63] In addition, access to tools and expertise will be required to achieve battlespace knowledge. What is of value and what is likely to distract depend to a great extent upon what the entity is supposed to do. Part of the challenge faced will be to develop a better understanding of situational needs and to provide the necessary education and training to deal with the explosion of information.

Virtual Collaboration

In this chapter, we have examined the nature of the benefits that can be obtained by sharing information and assets. Earlier the point was made that the robust networking of the warfighting ecosystem enables new kinds of relationships to develop. One of the most powerful relationships that emerges is virtual collaboration. Virtual collaboration goes far beyond simple sharing of information. It enables elements of the warfighting ecosystem to interact and collaborate in the virtual domain, moving information instead of moving people and achieving a critical knowledge mass. Key component technologies such as video teleconferencing (VTC), virtual whiteboards, and collaborative planning applications enable virtual collaboration.

Virtual collaboration in the information domain has numerous operational benefits. For example, virtual collaboration enables the times associated with existing planning and execution process to be reduced. These savings provide additional time to rehearse, move to contact, or sleep. The net result is increased effectiveness.

In Expeditionary Aerospace Operations, moving information instead of people changes the dynamics of the force deployment process by enabling split base operations. The concept has proven to be promising during *Expeditionary Force Experiment '98*. Split base operations has the potential to both decrease the time required to initiate air operations and free up transport aircraft to move combat capability into theater. The ability to move information instead of people also has significant benefits in other areas. The seven examples that follow highlight some of the benefits of the shift to network-centric operations.

Example 1: *New Relationships Between Commanders—Battle Command via VTC*

Old Way: Corps and division commanders travel across the battlefield to be in the same place at the same time to plan ground operations.

Network Centric Warfare: Commanders interact via VTC, which results in a significant reduction in planning time and elimination of time to travel.

Value: Decreased planning time provides commanders with the operational flexibility to enable their forces to rehearse, move to contact, re-supply, repair, or rest. Net result is increased combat power.

Concept Status: Demonstrated by U.S. Army in operational exercises.

Example 2: *Split Base Operations*

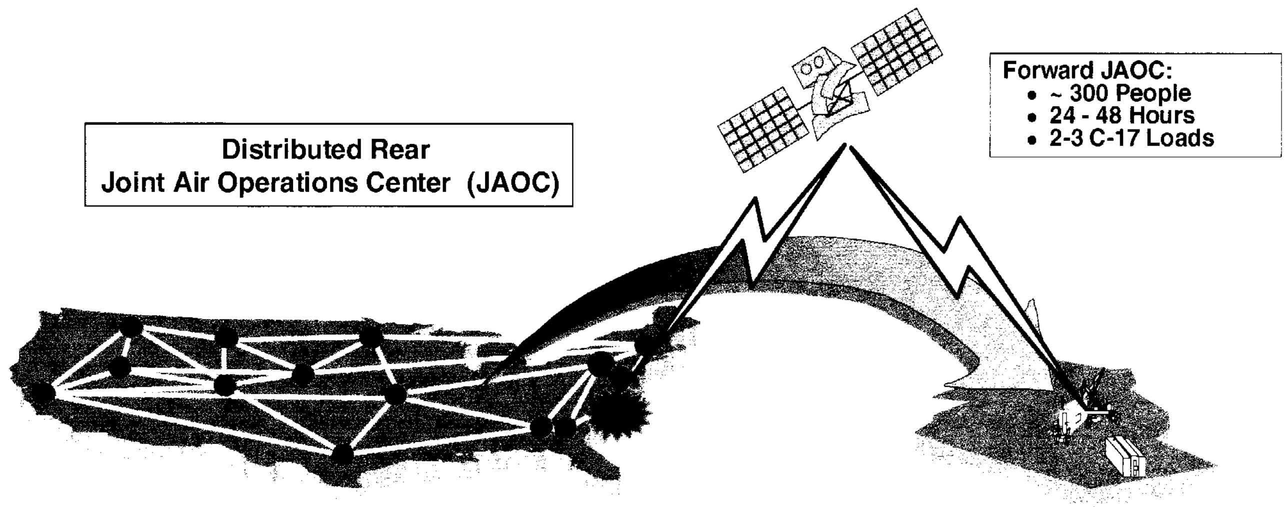
Old Way: Air Force deploys 1,500 to 2,000 warriors into theater to set up and operate a Joint Air Operations Center. Moving the personnel and equipment requires 25 C-17 missions and takes over 10 to 15 days.

Network Centric Warfare: Air Force moves an order of magnitude less people into theater to operate a Forward Joint Air Operations Center (JAOC), which is supported by a robustly networked force in the form of a Distributed Air Operations Center based in CONUS. With a significantly reduced logistics footprint, the forward JAOC can be deployed into theater with less than five C-17 missions and be operational in 24 to 48 hours from receipt of deployment order.[64] This concept is portrayed in Figure 16.

Value: Air Operations Center is operational in 24 to 48 hours, enabling operational commander to more effectively employ expeditionary Air Forces moving into theater. Furthermore, the C-17 missions which are freed up can carry enough material to deploy two Tactical Fighter Wings into theater.

Concept Status: Explored by the U.S. Air Force in *Expeditionary Force Experiment '98.*

Example 3: *Virtual Support Services*



Source: Aerospace C2 Agency

Figure 16. Virtual Collaboration—Moving Information, Not People

Old Way: Supporting staff such as dispersing clerks, radiologists, and weather officers deploy with operational units.

Network-Centric Operations: Specialists provide virtual services from centralized locations by moving information.

Value: Improved services, provided at reduced costs, enabled by massing of intellectual capital in centralized locations in the continental United States.

Concept Status: Operational.

Example 4: *Quality of Life*

Old Way: Deployed forces communicate with families and loved ones via mail or telephone, at infrequent intervals.

Network-Centric Operations: Deployed forces communicate with families and loved ones with increased frequency and timeliness via e-mail (potentially on a daily basis), telephone, or VTC.[65]

Value: Deployed warfighters are able to solve family problems in close to real time (e.g., finance), interact with their children, and experience their children's lives while they are growing up. Worry goes down, morale goes up, and operational effectiveness remains at a higher level over long deployments.[66]

Concept Status: Operational.

Example 5: *Distance Learning*

Old Way: Units release warfighters to attend training or education events away from their units.

Network-Centric Operations: Education is provided to warfighters deployed with their units via VTC or compact disk (CD).[67]

Value: Manning levels are maintained and opportunities for education and training are available to all deployed forces. Operational proficiency and morale increase.

Concept Status: Operational.

Example 6: *Collaborative Mission Planning*

Old Way: A complex multi-aircraft strike takes hours to days to plan employing traditional techniques. The challenges of synchronizing and de-conflicting multiple strike packages require multiple planning iterations.

Network Centric Warfare: Collaborative planning tools enable strike planners, potentially based on multiple ships or in units ashore, to plan and de-conflict multi-aircraft strike packages.[68]

Value: Improved capabilities for synchronization and de-confliction significantly decrease planning time and provide aircrews with the operational flexibility to rehearse or accelerate operational tempo. Net result is increased combat power.

Concept Status: Operational.

Example 7: *Joint Intelligence Virtual Architecture (JIVA)—Virtual Collaboration for Intelligence*

Old Way: Intelligence analysts operating in geographically distributed locations have a limited capability to interact and collaborate on intelligence products. Stove-piped intelligence dissemination systems limit access to intelligence products and provide a limited capability to search or browse databases and perform comparative analysis.

Network-Centric Operations: Collaborative tools enable intelligence analysts based worldwide to collaborate in the development of intelligence products. Sophisticated data mining and data warehousing applications provide intelligence analysts with significantly improved access to large volumes of source data for analysis and integration.

Value: Significantly improved intelligence products and worldwide access to these products.

Concept Status: Ongoing development and deployment in the Intelligence community.

Battlespace Entities

The task at hand is to design a set of battlespace entities and a set of interconnections (an enterprise of networked or linked entities) that can take full advantage of the increased amount of information available, turn this information into knowledge, and generate increased combat power. In other words, leverage shared battlespace awareness to allocate, assign, and employ assets and then modify these allocations, assignments, and employments as awareness of the situation changes. In some operational situations, a desired objective is to achieve battlefield results that approach a *global optima* without using a centralized approach, thus avoiding the significant shortcomings associated with centralized approaches. In other operational situations, a premium must be placed on flexibility and adaptability vice solely focusing on optimization. Consequently, the concept of *dynamic fitness* must play a key role in both the design and employment of forces.

Transforming NCW from a concept into a reality requires that we define the battlespace entities (their roles, responsibilities, tasks, and decisions), their connectivity (links among them), and the nature of the information and products that are exchanged (the degree of coupling).

It is the extent and nature of the interactions among battlespace entities that generate the power of

NCW.[69] We have chosen to focus this discussion on battlespace entities somewhat abstractly to illuminate the underlying fundamentals of NCW. Battlespace entities have three primary functional modes: sensing, deciding, and acting. The degree to which one functional mode dominates at a particular point in time determines the role of an entity in a military operation. Entities that have a primary function of sensing are called sensors. Sensors include all entities that contribute to battlespace awareness, from satellites to "eyes on the ground." Actors are those entities that have the promary function of creating "value" in the form of "combat power" in the battlespace. Actors employ both traditional (lethal) and nontraditional (nonlethal) means. Decision makers perform a variety of functions (e.g., making resource allocation decisions) and are found at all levels of the organization. Battlespace entities will need to be connected in some fashion, but how they need to be connected is not predetermined. Moreover, we do not want to imply a universal connectivity where every node is directly connected to every other node, or that all nodes are provided with the same level of information services. That being said, NCW is based upon sharing information and assets to achieve synergistic, collaborative effects, and it is unlikely that the proper degree of coupling can be realized without having a high-performance, communications, and computational capability providing access to appropriate information sources, and allowing seamless interactions among battlespace entities in a "plug and play" fashion. This is called the "infostructure." Determining the nature of this enabling infostructure and the best way to acquire it present significant challenges.

There has been a tendency, in the effort to explain NCW, for its proponents to speak in conceptual terms, and others to hear in literal terms. NCW can only be effectively reduced to simple vu-graphs if everyone understands that the links portrayed are only notional, and that in reality it is the specifics that count—which links exist, what information is passed, and what is done with the information.

It is not hard to understand a battlespace with three kinds of entities. Everyone seems to understand that these can be located throughout the battlespace (either in fixed locations or increasingly as mobile) and that a wide variety of sensors would exist. Further, there seems to be no difficulty when it comes to the notion that some entities may, in fact, have complex functionality—e.g., perform the roles of sensing and acting at the same time. The difficulty seems to be in understanding the nature of the links among entities, and in appreciating the combat power associated with the network-centric operations that the links enable.

The nature of the connectivity and the division of responsibilities remain the central issues that need to be explored as experimentation with NCW begins. It is here that some confusion exists. This confusion is a result of the tendency to move from the specific to the collective as the discussion shifts from entities to links.

From this collective, or global, vantage point a collection of sensors (or as it is often depicted, a "network of sensors") can be viewed as providing the information from which battlespace awareness is generated. This sort of picture implies that somehow all of the sensors are actually linked together. While this makes sense conceptually, it may not make sense in practice. NCW focuses attention both on the appropriate linking of sensor entities, and on the contributions they make to generating shared battlespace awareness. Developing shared battlespace awareness requires that sensor entities (or rather the information they generate) be linked in some fashion. This does not mean that all sensor entities need to be *directly* linked to one another; neither does this mean that they all need to be linked into a single sensor network. In most cases, sensor networks require only that a subset of battlespace sensors be task organized and provided with high performance information services. Shared battlespace awareness requires that the information collected by sensors be put in a form that makes it possible for other battlespace entities (but not necessarily all others) to fuse appropriate information, place it in context, and understand its implications. This will permit the sharing of information that is so important to begin reaping the potential power of NCW.

From a global vantage point, battlespace awareness seems as if it exists as a single thing. Battlespace awareness really exists in a distributed form. We really only see a slice of it at one time—either a particular detail or a gross overview without details. In fact, research results indicate that the ability to move up and down levels of abstraction without introducing distortions distinguishes effective from ineffective utilization of knowledge. This tendency in discussing NCW to move from the global or collective vantage point (where we consider conceptual relationships) to the specifics (where we think about actual links among entities) has created confusion about what NCW really means and the ways to achieve it.

In the same way that sensor entities will be linked to many more entities than they currently are, so will actor entities be more richly linked as well. Again, this does not imply all actors will be linked to an actor network, or exclusively or primarily to other actors. Rather that actors (e.g., shooters) will have a far richer collection of links to other battlespace entities than they do with platform-centric operations. In the future they will be linked to each other, directly to sensor entities, or indirectly to sensor entities by virtue of having direct access to their products (individually and/or collectively).

The purpose of linking actor entities in this fashion is to make them better informed and to increase their overall effectiveness. Making them better informed means they need to know more not only about the classification and position of enemy assets, but also about a host of other things. For example, they need to know the overall situation, the commander's intent, the current and planned positions, and the intended actions of other battlespace entities, including neutrals. With this increased knowledge comes better understanding, which carries with it the ability to do a better job of developing insights, and generating combat power.

This brings us to the relationships that sensor and actor entities will have with decision (or command) entities. Obviously, decision entities must be linked to both sensor and actor entities, as well as to other decision entities. The link between a decision entity and a sensor entity (or entities) can be either direct or indirect. The link may transfer raw data or products. It may be one-way, two-way, or interactive. These are only some of the possibilities. Decision entities may be linked to other decision entities and actors in a similar variety of ways.

NCW has often been articulated somewhat abstractly where sensors and actors are richly interconnected. This is a conceptual representation and should not be taken literally. The point to be made is that information collected by sensors can be brought to bear in a far more flexible way than is currently possible, with the selection of the actor not being as restricted as it currently is in platform-centric configurations.

A major difference between NCW and traditional approaches to warfare is that in NCW, actors (shooters) do not inherently own sensors, and decision makers do not inherently own actors. In platform-centric operations, platforms own weapons and weapons have their own organic sensors. For example, in the Air Defense Mission Area, the commander of a Hawk Missile Battery has dedicated sensors and absolute control over the employment of his missiles. His organic sensing capabilities cannot be exploited by others and his weapons cannot be assigned by others. In contrast, with NCW, all three types of entities work collaboratively in response to the dynamics of the battlespace to achieve commanders' intent. This enables decision and actor entities to play a wide variety of roles. The net result will be a dynamically re-configurable force that can take on the characteristics best suited for fast-paced battlespace domains where opportunities are fleeting and delay can be fatal. Continuing the Air Defense example with network-centric operations, the operational constraints that are currently associated with platform-centric operations may be eliminated in situations when it would make sense for a Hawk Missile Battery's sensors or missiles to be tasked by another battlespace entity, such as a commander with responsibilities for the Joint Theater Air and Missile Defense Mission.

This does not imply that it is a "free for all" on the battlefield; rather, the point is that all assets can be employed more flexibly, resulting in a more agile force. Exactly how this aspect of NCW will work remains to be developed as part of the implementation of JV2010, particularly the series of Joint experiments that will be an integral part of this process. NCW is offered to provide a rich source of hypotheses to be tested and refined, and a conceptual framework to focus the experiments and analyses ahead.

We have seen how NCW frees us from a host of constraints that currently restrict how we use the information our sensors generate, and how we employ our actors. We also have seen how breaking down these constraints offers the opportunity to reap the power of the network that is inherent in Metcalfe's Law. In the next chapter, the roles of battlespace entities are discussed in detail, and the coupling of these entities, combined with increases in weapons reach, improved maneuverability of armored forces, and enhanced precision weapons, will enable a vastly increased speed of command which can generate more force effects in a given period of time.

Although we still have a tendency to use the vocabulary of combat at the tactical level, NCW is applicable to all levels of warfare and contributes to the coalescence of strategy, operations, and tactics. Its ability to contribute to military operations by increasing shared awareness extends to a wide variety of missions, force sizes, and force compositions.

Roles of Battlespace Entities

Each of the entities in the battlespace can add value to the mission by contributing to:

1) Battlespace awareness and knowledge
2) Command and control and decision making
3) Execution

Thus, generally speaking, the collection of sensor entities contributes information which forms the basis for battlespace awareness and knowledge; the set of decision entities collectively exercises command and control by accomplishing planning and battle management; and the collection of actors executes the plan. The Information Age, however, is already bringing about changes that will ultimately merge battle management, planning, and execution into an integrated, dynamic adaptive progress. This will require effective interactions between not only decision entities and actors, but also sensors.

Figure 17, Roles of Battlespace Entities, depicts the respective roles and nature of the interactions among sensor, actor, and decision entities as we close out the 20th century and project the 21st century. A number of common operational pictures (COPs)[70] are depicted, each one of which can have more than one view. A view is usually a subset of information in the COP aggregated and displayed in a particular way to support a decision or task. COPs serve to ensure there is functional consistency among the different views. Currently, COPs are mainly a work in progress. Significant inconsistencies still need to be addressed. How best to do this, and the problems associated with achieving a common perception of a situation, remain topics for research and experimentation.

In Figure 17, decision makers and actors are organized into a hierarchy (the triangle), and each entity is connected to other entities. Sensors provide the data they collect either to data storage centers that support one or more COPs, as well as directly to selected actors. Decision entities can task a limited number of sensors, view COPs, and direct (command and control) actors. The limits are a function of our legacy, stove-piped environment. Actors get the information they need in a number of ways, either directly from selected sensors, locally stored static databases, or by viewing selected COPs, which are constantly being updated. Actors can also contribute information to data centers and communicate with other actors, passing information or commands back and forth.

Figure 17 also depicts how we expect the relationships among battlespace entities to evolve over the next few decades (21st century) as we strive to increase our knowledge of the battlespace. Depicted are the:

1) increased linkages among battlespace entities existing in the 21st century;
2) integration of various COPs, resulting in fewer COPs, each with the ability to

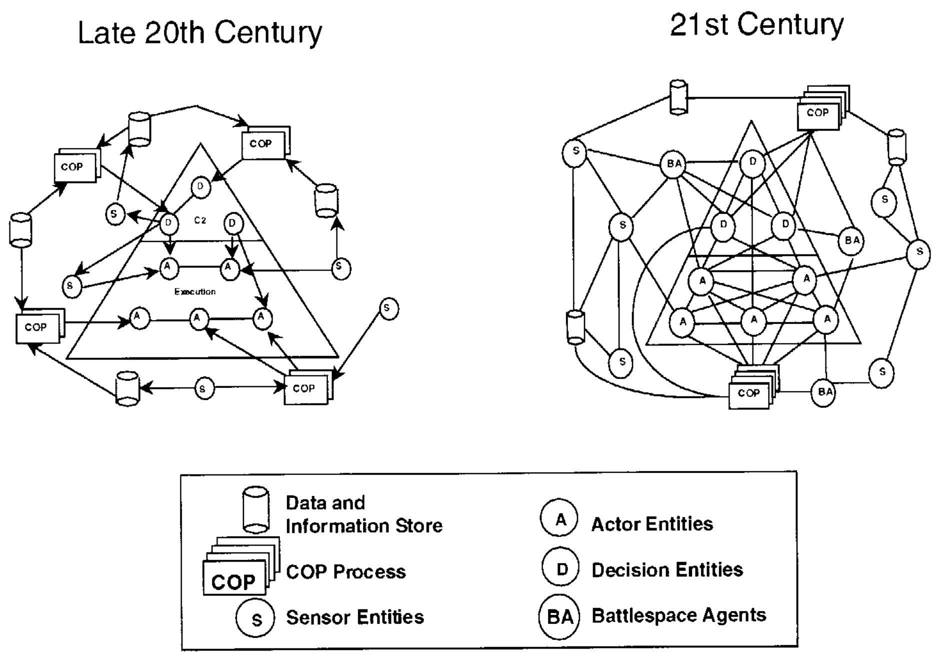


Figure 17. Roles of Battlespace Entities

provide an increased number of tailored views; and
3) introduction of battlespace agents which perform selected tasks as delegated by decision and actor entities.

These battlespace agents may take the form of any one of several automated decision or information processes, including decision aids, expert systems, trained neural nets, or genetic algorithms, each autonomously performing selected tasks for decision or actor entities.

To a great extent, only our imagination and willingness to employ them will limit the potential contribution of battlespace agents to the warfighting enterprise. The extent to which decisions will be delegated to agents will be hotly debated. However, we will, driven by the complexity and operating tempo of the Information Age, find it necessary to make judicious use of these Information Age capabilities in the 21st century.

When considering the pros and cons of delegating a particular task, or set of tasks, to battlespace agents, it is important to recognize that under the pressure of time or uncertainty, some of today's decisions are made either by default or by individuals who may not have all the expertise or even training or experience necessary to be proficient. Among the tasks that these agents are likely to perform are:

1) requesting additional information as required by the situation;
2) tasking sensors;

3) notifying decision entities of things that require immediate attention;
4) translating a commander's intent into messages or instructions implementing the intent;
5) identifying and resolving inconsistencies within a COP; and
6) developing and red teaming plans.

A discussion of the nature of the changes that can be expected in battlespace entities, and the links among them, is the subject of the next chapter. In turn, this chapter deals with the major tasks that need to be accomplished:

1) achieving battlespace awareness and knowledge;
2) providing command and control; and
3) execution and decision making.

The key to understanding the roles of and the relationships among battlespace entities is to focus on processes that turn raw data into information, and information into knowledge. Since each of these information-related terms is used rather loosely in everyday speech, and the two are often used interchangeably, we will briefly define this hierarchy of terms.

Data are individual facts, measurements, or observations which may or may not be sufficient to make a particular decision. Information is obtained when elements of data are assembled, reconciled, fused, and placed in an operational context. Knowledge is derived from being able to use information to construct and use an explanatory model based upon an understanding of the situation or phenomenon. Such a model allows us to forecast future states, predict outcomes, and also contributes to our ability to control the situation—or to be proactive rather than reactive. This is, of course, a primary goal of command and control.

Battlespace awareness results from the fusion of key elements of information which describe or characterize the battlespace. The elements are primarily explicit information (e.g., position of forces, geography, and weather). This type of information needs little interpretation and usually can be communicated quickly and easily. The vast majority of information in the common operational picture is explicit information. The difficulty comes in placing the information in a larger context and understanding its implications.

Sensor entities are key contributors to battlespace awareness. As is described in detail in the sections that follow, shared battlespace awareness is fundamentally a network-centric capability.

In contrast, battlespace knowledge consists of tacit information. Tacit information requires interpretations. While supporting "facts" can be easily transferred, the underlying organizing logic can seldom be transferred quickly and easily.[71] Examples of tacit information include capabilities and tactics of an adversary, local customs, and intent. Consequently, battlespace knowledge should be viewed as a people-centric capability in the sense that knowledge workers play a key role in developing, processing, and communicating tacit information.

Actor and decision entities can exploit battlespace awareness and knowledge by bringing various types of "models" to bear. They use doctrinal models, decision aids, expert systems, or the modeling services of an anchor desk that provides a reach-back capability to nondeployed entities. Hence, battlespace knowledge results in value added processes that use:

1) the experience of commanders and staffs; and
2) decision aids, simulation models, knowledge (expertise) located at a distance, and forms of AI and expert systems.

Actors can act upon any of these levels of information. However, their effectiveness in the specific and in the collective will differ as a function of the level of information that is acted upon and the timeliness of the actions. The tradeoff is between the quality of information available and the time to act. NCW should result in making more quality information available in a more timely manner.

Recent military operations in Kosovo during *Operation Noble Anvil* highlighted the power of new types of relationships among sensors, deciders, and actors that are possible with a network-centric force. Figure 18 portrays the information flow and operational tasks associated with the operation of the Predator UAV. The sensor was operated by actor entities located at one geographical location. The information collected by the sensor was analyzed by decision entities at multiple geographically dispersed locations. The information was then transmitted in near real time to decision entities located on command and control platforms and then to actor entities in the form of shooters, which engaged the targets sensed by the UAV.

In another operational situation, the roles of entities were reversed in real time to execute the mission. In this scenario, a pilot operating as the Forward Air Controller (FAC) (as a decision entity) had designated a target for engagement by a pilot operating strike aircraft (the actor). However, the strike aircraft had already expended the optimum weapon to engage the target, and its remaining weapons could not provide the required lethality. However, the aircraft operating as the FAC was loaded with munitions more appropriate for engaging the target. Consequently, the two aircraft switched roles. The strike aircraft took on the role of the FAC in designating the target, and the aircraft operating as the FAC engaged the target. When the engagement was complete, the aircraft operating initially in the role of the FAC reverted to operating in this role.

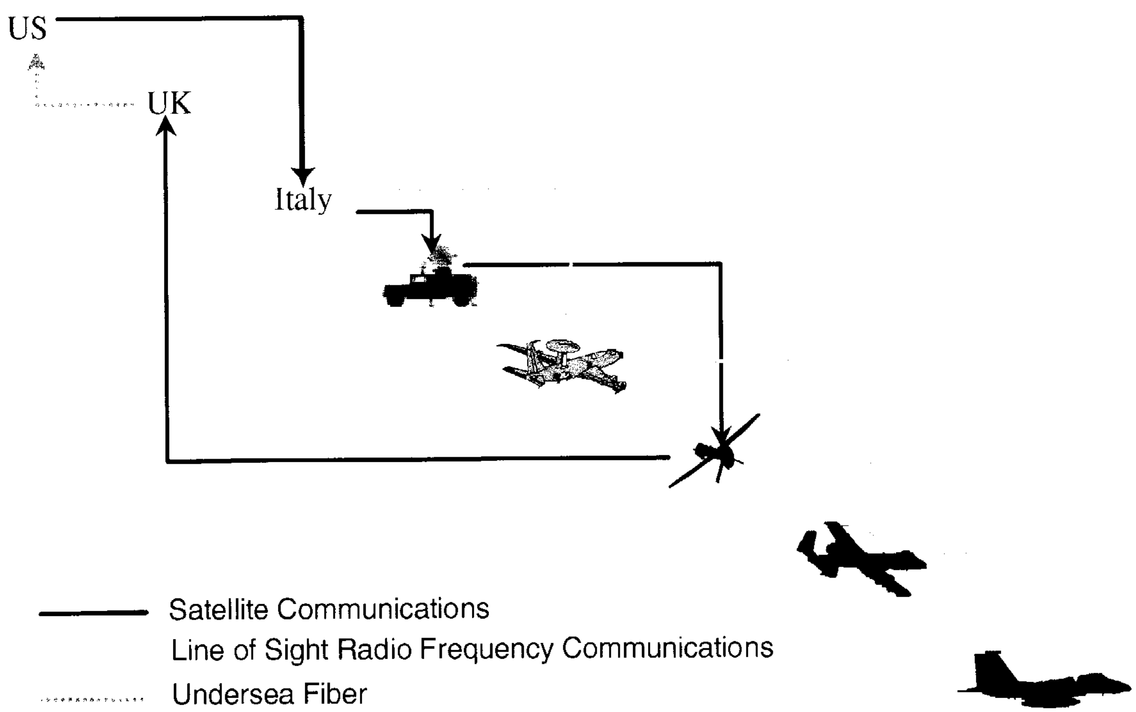


Figure 18. Relationships Between Entities in a Network-Centric Operation

Battlespace Awareness and Knowledge

Achieving high levels of battlespace awareness and knowledge lies at the foundation of Joint Vision 2010. NCW enhances the ability to develop and maintain battlespace awareness and knowledge by capitalizing on capabilities for collecting, processing, and transporting available information.

Battlespace knowledge is derived from shared battlespace awareness and involves the fusion of information into a set of COPs and the dissemination and display of COPs as shown in Figure 19. Providing battlespace awareness to warfighters across the Joint force with requisite accuracy and timeliness requires that data and information from multiple sources be collected, processed (analyzed when necessary), transported, fused, placed in appropriate contexts, and presented in ways that facilitate rapid and accurate inferences. It also requires that actors and decision entities be provided by training with internal models and/or decision aids or models. With this insight, we can observe that it requires both battlespace awareness and these cognitive models to generate battlespace knowledge which is in and of itself, an emergent network-centric property.

Examples of information concerning friendly, enemy, and neutral forces that can be integrated in a COP include:

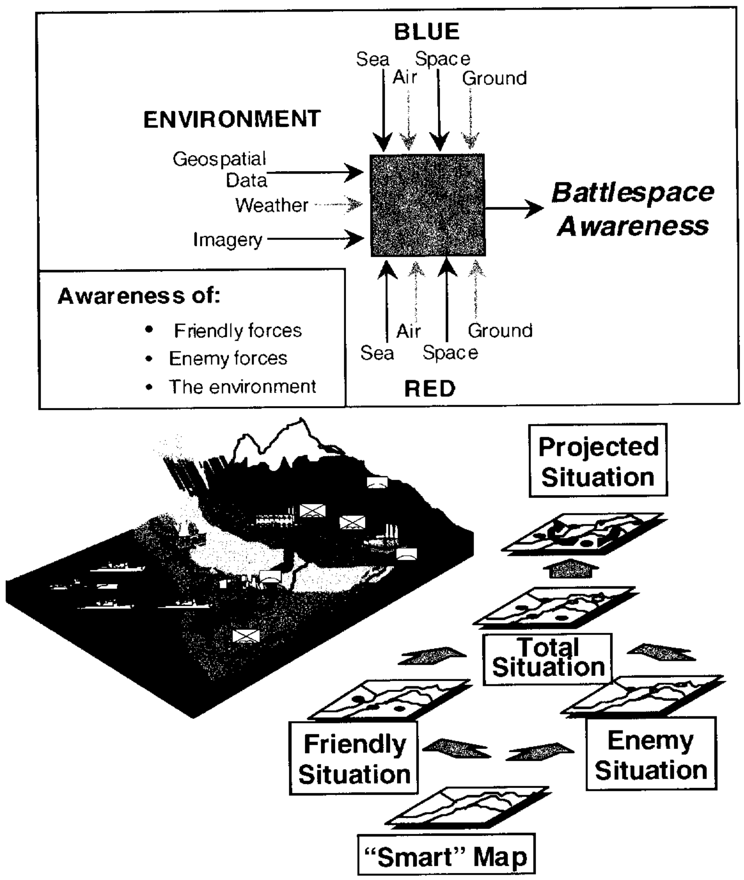


Figure 19. Elements of Battlespace Awareness

1) location (current positions, rate of movement, and predicted future positions);
2) status (readiness postures including combat capability, whether or not in contact, logistics sustainability, and so forth);

3) available courses of action and predicted actions for enemy forces (force information also includes the capabilities of offensive and defensive enemy weapons systems and damage assessment as a result of friendly actions);
4) the environment (including current and predicted weather conditions, the predicted effect of weather on planned operations and enemy options, and terrain features such as trafficability, canopy, sight lines, and sea conditions).

Shared battlespace awareness emerges when all relevant elements of the warfighting ecosystem are provided with access to the COP. This means that battlespace awareness must be viewed as a collective property (a type of collective consciousness). It does not exist at just one place (node) in the battlespace, but rather at all relevant nodes in the battlespace—across echelons and functional components. The degree of detail that is portrayed in an operational picture can and most likely will vary by echelon. For example, Figure 20 portrays a snapshot of the level of information provided by a COP available to the Brigade Commander during the Task Force XXI AWE. The degree to which the information content of an operational picture can vary across echelons to enable relevant information to be portrayed clearly and unambiguously to decision makers and actors is portrayed in Figure 21, Variation in Information Content for Operational Pictures.

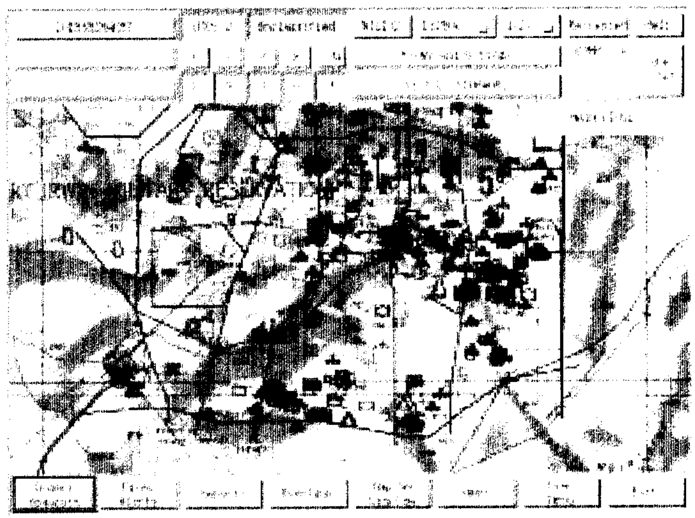


Figure 20. Common Operational Picture at the Brigade Level

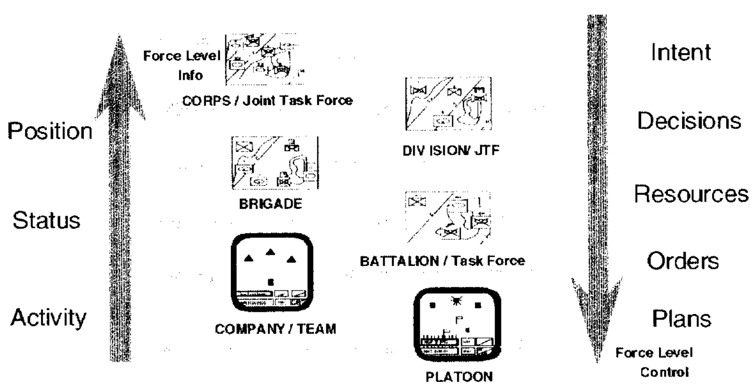


Figure 21. Variation in Information Content for Operational Pictures

The information for generating battlespace awareness will be provided by numerous sources. For example, information on red forces can be collected by intelligence, surveillance, and reconnaissance platforms operating as part of a sensor network, sensors employed on weapons platforms, or human assets on the ground (e.g., manned reconnaissance teams). A shared awareness of blue positions across the battlespace can be generated by enabling all elements of the blue force to transmit their current position information and receive relevant position information from other entities. Each element of the blue force can establish its position in the battlespace with a high degree of accuracy through use of precision navigation systems like the global positioning system (GPS). Blue status information, such as fuel remining and weapons loading, can be generated using embedded sensors that track consumption of fuel and ordnance. Real-time operations data can also be collected (e.g., information on engine and transmission loading and use), which in turn can be employed to dynamically maintain current levels of operational readiness by more accurately predicting maintenance requirements. Environmental information can be collected with traditional sensor types (e.g., weather, imaging, ocean sensors, etc.), potentially augmented with information from sensors on weapons systems.

Generating shared awareness of blue requires that we have a mechanism in place to dynamically capture position, status, and intent information from all elements of the blue force and have the capability to provide relevant information on blue to those who need it. For this to happen, all relevant elements of the blue force need to be contributors to the process—they need to be connected to the network. In order to achieve battlefield awareness and then to achieve battlefield knowledge, we need to move beyond information that tells us where things are and provide information about their identities. It is also necessary to know something about current operational status and capabilities, as well as doctrine and intent.

Similarly, if information on red forces, or the environment, generated by a subset of the force (e.g., intelligence systems, sensors on board weapons platforms), is to be combined with blue force information to generate battlespace awareness, it needs to be distributed to all relevant elements of the warfighting force.

The ability to develop accurate and timely source information for battlespace awareness depends upon the characteristics of the information processes available and the performance of the network. For example, the accuracy of distributed position information on moving targets (friendly, neutral, red) is a function of not only collection and analysis processes, but also the relative velocity of objects and the velocity of information within the blue network.

For example, if a blue weapons platform, such as an AH-64D Longbow Apache, detects a column of tanks, its onboard sensor is capable of generating engagement quality information on most if not all of the tanks in the enemy formation. This information has significant potential value to the warfighting force. The value of this information is a function of who it can be shared with (e.g., decision and/or actor entities) and the timeliness of the information sharing. For example, if the Longbow Apache can transport engagement quality awareness to an artillery battery in real time, then the potential exists for the blue force to mass the effects of direct and indirect fires. If the information cannot be transmitted in real time, than an opportunity for massing effects is lost. However, if information on target positions collected by the Longbow Apache can be transmitted, but not in real time, the information may be accurate enough to enable close air support assets to subsequently acquire and engage the column of tanks.

Similarly, if a commander desires to increase the velocity of maneuver of his or her force and simultaneously maintain battlespace awareness, then the velocity of information must increase with the velocity of maneuver. For example, we can observe that as the average velocity of blue force increases, the instantaneous accuracy of shared position information will decrease if the average velocity of information does not increase as well. This occurs because instantaneous accuracy is a function of data latency. Simplified, using a constant position update rate, the instantaneous position error of a weapons platform, moving at 500 miles per hour (such as a fighter aircraft), is potentially 10 times larger than for a platform moving at 50 miles per hour (such as a tank).

In summary, the accuracy of the information in a COP is a function of the accuracy of source information, velocity of information between nodes in the network, and velocity of the objects of interest in the common operational picture.

Our ability to provide relevant battlespace entities with access to information can be exploited to increase the accuracy of our information about enemy assets. The specifics of how an increased velocity of information can be used to increase battlespace awareness is discussed below.

Sensor Networks

The operational performance of a sensor network (a collection of networked sensor entities) in generating battlespace awareness depends upon a number of factors including:

1) the performance of component sensors;
2) sensor geometry: the locations of the sensors with respect to each other and the objects of interest;
3) the velocity of information;
4) fusion capabilities; and
5) tasking capabilities.

In the fundamental shift to network-centric operations, sensor networks emerge as a key enabler of increased combat power. The operational value or benefit of sensor networks is derived from their enhanced ability to generate more complete, accurate, and timely information than can be generated by sensors operating in stand-alone mode. The performance advantage that emerges from the enabling of sensor networks is a function of the type of sensors being employed (e.g., active, passive) and the class of objects of interest (e.g., missiles, aircraft, tanks, submarines, etc.). Sensor networks can generate significantly increased battlespace awareness of objects in the battlespace.

Sensor networks provide significant performance advantages over stand-alone sensors in key mission spaces by overcoming the fundamental performance limitations (e.g., coverage, accuracy, and target identification properties) of individual stand-alone sensors. The value-adding processes of data fusion and sensor tasking can partially overcome these limitations. This does not imply that the level of awareness generated against all targets will be 100 percent in all mission areas, but rather that almost all mission areas can benefit to some degree from the shift to network-centric operations. A few examples follow.

Application of Sensor Networks to the Surveillance and Tracking of Objects in Air and Space

Active Sensors. Against objects moving in air and space, active radar sensors can provide very accurate ranging measurements and less accurate azimuth and bearing measurements. When errors in range and bearing are factored into estimation and prediction algorithms, the net result is an error ellipsoid which describes the uncertainty associated with a track in three dimensions. In addition, when radars are employed in the operational environment, scattering and environmental effects can combine to degrade the detection and tracking capabilities of stand-alone radar sensors, particularly against stressing targets (e.g., high speed, low observables).

Under operational conditions, the tracking performance of stand-alone sensors can degrade. This drop off in sensor performance can be manifested in track discontinuity, unacceptably slow track convergence, or in the worst case, inability to initiate a track. These performance limitations can be overcome by using information from two or more sensors, enabling data fusion and sensor tasking. Sensor fusion enables measurements from two or more sensors to develop a composite track. (This fusion process is portrayed in Figure 22.) The error ellipsoids that characterize the composite track converge much more rapidly to a level of accuracy that permits engagements (engagement quality awareness) when information from multiple sensors is available and utilized. Figure 23 portrays the ability of fusion to decrease the time required to generate engagement quality awareness.

Sensor tasking can further enhance performance. Sensor tasking enables sensor resources to be dynamically focused on high priority sectors of the battlespace. This enables a scarce sensor resource to serve many customers, and helps ensure that the right mix of sensors is available at the right time. For example, a stand-alone phased array radar exploits sensor tasking by tasking beams to operate in either broad area search mode or track mode. The operational benefit of sensor tasking is enhanced when sensors from multiple platforms simultaneously focus their energy on the same object. A functional model of the dynamic sensor tasking process is portrayed in Figure 24. The resulting increase in tracking performance, resulting from dynamic sensor

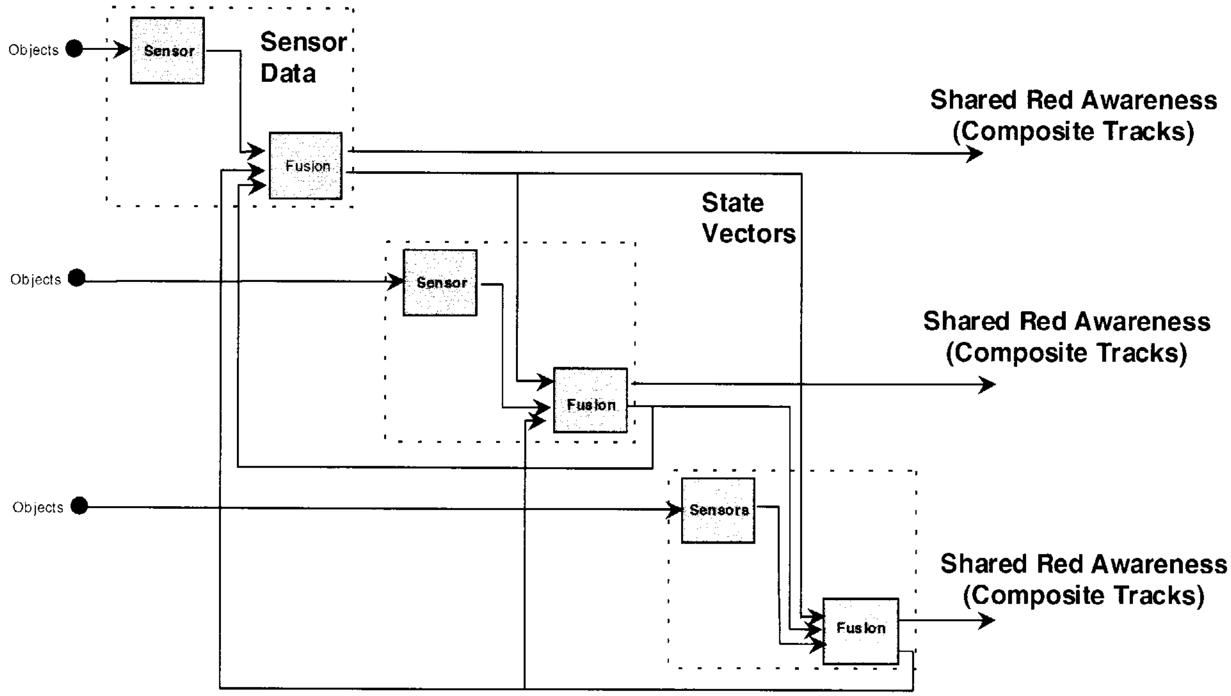


Figure 22. Network-Centric Operation of Data Fusion

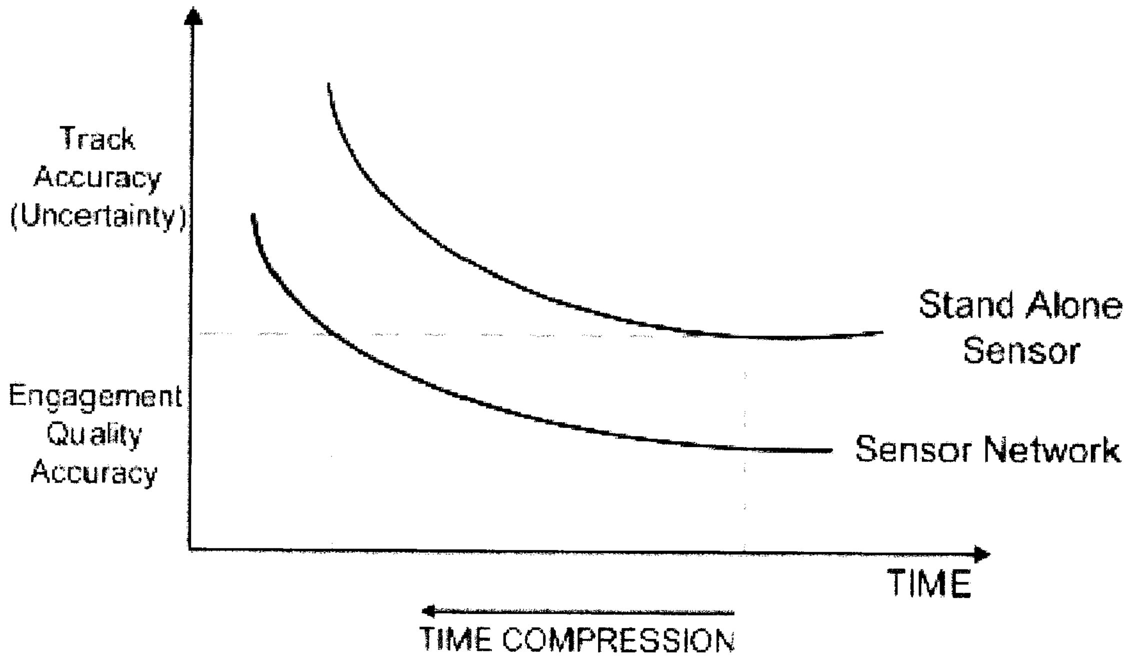


Figure 23. Decreased Time Required to Generate Engagement Quality Awareness

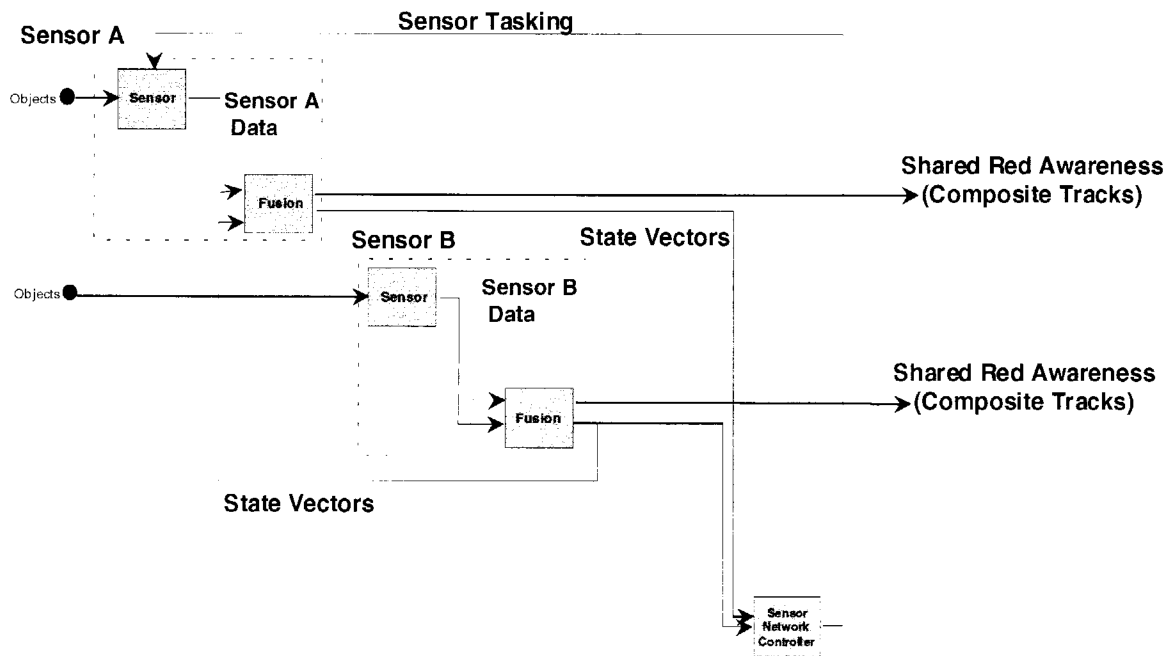


Figure 24. Sensor Tasking

tasking, can be quite significant, particularly against stressing targets.

The U.S. Navy's Cooperative Engagement Capability (CEC) provides proof of the existence of the power and operational benefits of NCW. The CEC generates increased battlespace awareness by fusing data from multiple sensors and enabling quantum improvements in track accuracy, continuity, and identification over the information that could be achieved by using stand-alone sensors. The performance in tracking improvement associated with the embedded CEC sensor network is portrayed in Figure 25.

The CEC, by also linking actor entities together, is able to exploit this improved information to increase combat power by extending the battlespace, enabling incoming targets to be engaged at greater ranges and in depth with multiple shooters yielding increased probability of kill.

Passive Sensors. The performance limits of stand-alone, passive sensors operating against objects in air and space can also be overcome through employment of sensor networks. For example, passive sensors, designed to detect and track objects moving in air and space (e.g., missiles, post-boost vehicles, re-entry vehicles, satellites, debris), can only measure azimuth and elevation (and rates) directly. Range information can be inferred but cannot be measured directly. Accurate tracking requires multiple observations (azimuth and elevation) to develop a track. Signature observables, such as plume intensity, are sometimes useful. In some cases, the proximity of an object to the earth (e.g., a missile in boost phase)

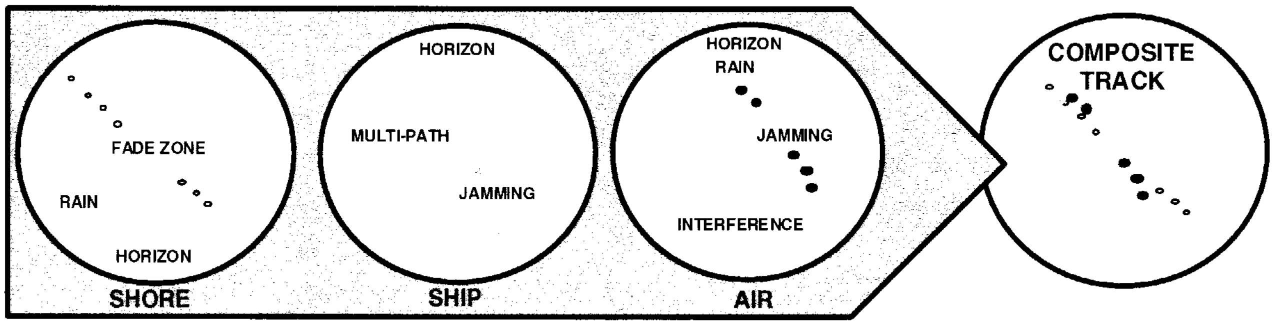


Figure 25. Formation of a Composite Track Within a CEC Sensor Network

can be exploited by a passive sensor to develop a more accurate track. The combination of sensor fusion and dynamic sensor tasking, made possible by linking sensors, can generate tracks on objects of interest that are significantly more accurate than those which can be generated by stand-alone sensors. Figure 26, Increased Battlespace Awareness Generated by a Sensor Network, portrays the operational benefit of a sensor network tracking a ballistic missile from launch until impact. The improved tracking accuracy of a sensor network is shown by the reduction in the size of the error ellipsoid vs. time.[72]

The Air Force Space Command's (AFSPACECOM) Attack and Launch Early Reporting to Theater (ALERT) capability provides an existence proof of the operational benefit of a sensor network in generating increased battlespace awareness against ballistic missiles.

The U.S. Navy's *Fleet Battle Experiment Series* has also demonstrated the ability for a sensor network consisting of ground- and sea-based radars to generate increased battlespace awareness against stressing targets in support of full-dimensional protection missions. During *Fleet Battle Experiment Delta*, land-based fire-finder radars and sea-based AEGIS radars were integrated into an experimental sensor network. This sensor network provided the ground component commander with significantly enhanced battlespace awareness to support the prosecution of the counter fire mission.

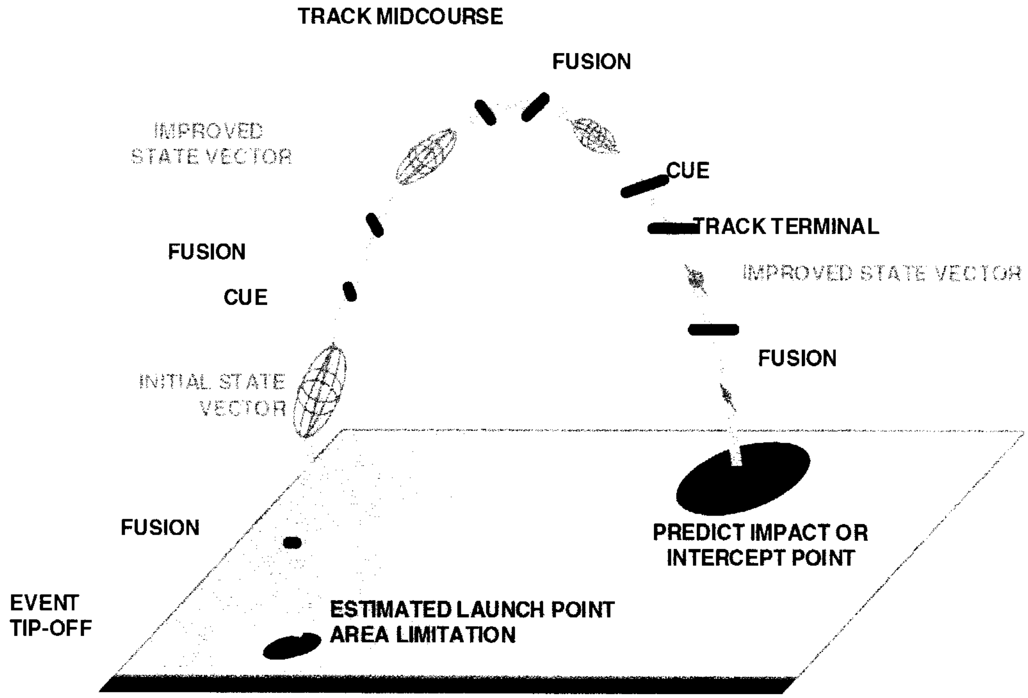


Figure 26. Increased Battlespace Awareness Generated by a Sensor Network

Application of Sensor Networks to the Surveillance and Tracking of Moving and Mobile Objects on the Surface of the Earth

Information about moving and mobile ground targets can also be improved by robustly networking sensors. Employment of sensor networks allows us to overcome line-of-sight obscuration by terrain, or environmental constraints imposed by weather. The combination of sensor tasking and data fusion enables multiple sensors, based in space, the air, or on the ground, to effectively increase the amount and quality of information available.

Certain classes of objects cannot be tracked, located, or identified with sufficient accuracy using a single type of sensor or sensor phenomenology. This deficiency can sometimes be overcome by linking sensors of different types to achieve an all source capability. Figure 27, Payoff of Sensor Fusion, portrays the significant reduction in position uncertainty that is possible with sensor fusion.[73] This increased performance is of particular value in detecting, locating, and identifying high-value targets, such as mobile surface-to-air or surface-to-surface missile launchers, as well as surface-to-surface missiles in flight. For example, information collected by a wide-area surveillance sensor, such as a radar MTI located on sensor platform such as a U-2 or an E-8 JSTARs, can be used to cue other sensor entities with different characteristics or capabilities such as imaging sensors, ELINT sensors, or manned reconnaissance teams. The operational concept of a multi-source sensor network was explored by the U.S. Marine Corps during the Hunter Warrior Advanced Warfighting Experiment